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Air Conditioning and Refrigeration Engineering
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Mollier chart

The state of refrigerant in a refrigeration cycle varies with a wide range of conditions while an air conditioner or a chiller is in operation.
When the changes in state under these conditions are plotted on a chart, each state and the numerical values of the state in every part of the equipment can be estimated.
Furthermore, the capacity or the operating state can be estimated using these values. This chart is called the P-h Chart.
The vertical axis of the P-h Chart specifies the pressure (P), and the horizontal axis specifies the specific enthalpy (h). The P-h Chart is therefore sometimes referred to as "Pressure-enthalpy Chart". Furthermore, this Chart has received another name derived from the name of the inventor of the Chart, that is, "Mollier (or "Morieru" in Japanese) Chart".
The P-h Chart consists of 8 kinds of lines in all; saturated liquid line, saturated vapor line, constant temperature lines, constant specific volume lines, constant dryness lines and constant specific entropy lines as well as constant pressure lines and constant enthalpy lines. It looks like a map, which shows the refrigerant properties diagrammatically. The methods of drawing the lines vary to some extent with the types of refrigerants, while the basic method of reading the lines does not vary. In this textbook, the R22 refrigerant (fluorocarbon: HCFC22, most-often used for air conditioning), is used as the teaching material. Furthermore, SI unit (International System of Units) is used to represent the unit.

2.1 Composition of P-h Chart

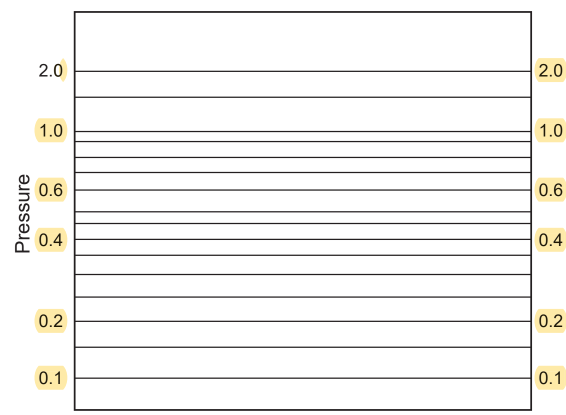
2.1.1 Pressure: P [MPa abs]

In the P-h Chart, pressure is graduated on the vertical axis. Therefore, horizontal lines represent constant pressure lines; and all points on the same horizontal line show the same pressure.
The scale is logarithmic but not required to be bound for use. The pressure scale is expressed in the value of absolute pressure.

Absolute pressure = Gauge pressure + Atmospheric pressure
[MPa abs] = [MPa G] + 0.1 [MPa abs]

Note: Under normal conditions, the "abs" of "MPa abs" is often omitted. In this textbook, however, the "abs" consciously remains shown for ease of understanding.

Fig.2-1



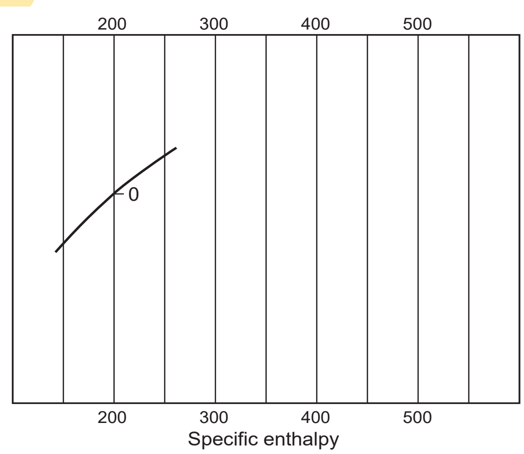
Q. 1

Chiller is operating with the use of R22 refrigerant. The low pressure gauge shows 0.5MPa G and the high pressure gauge shows 1.7MPa G. Show each of these pressures on the P-h Chart using horizontal lines.

2.1.2 Specific enthalpy: h [kJ/kg]

The specific enthalpy is graduated on the horizontal axis. Therefore, constant specific enthalpy lines are shown with vertical lines. This scale is proportionally graduated. Therefore, the numerical values must be read as accurately as possible.
The specific enthalpy is the sum of internal energy and work energy; which can be defined as the total amount of heat held by the refrigerant in a given state.
On the P-h Chart, the specific enthalpy of 1 kg mass of saturated liquid at 0˚C is defined as 200 kJ/kg.

Fig.2-2



Note: The specific enthalpy is scientifically defined as:

$h = ue + Pv$

h: Specific enthalpy
ue: Internal energy
P: Absolute pressure
v: Specific volume

2.1.3 Saturated liquid line and saturated vapor line

Liquefied refrigerant at its boiling point is a saturated liquid. A line connecting all boiling points is called the saturated liquid line.

Similarly, a vaporized refrigerant at its boiling point is a saturated vapor. A line connecting all boiling points is called the saturated vapor line.

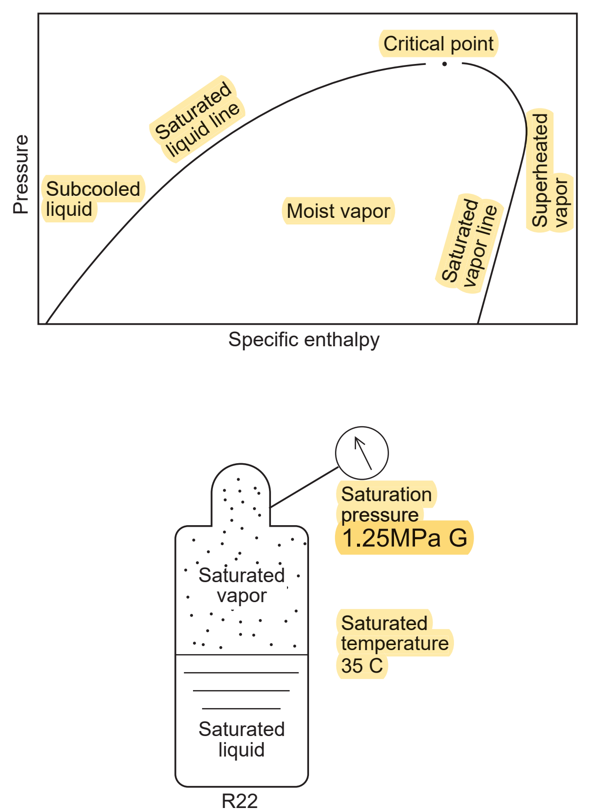
Saturated temperature equivalent to the pressure is graduated on these lines.

When liquid refrigerant of a given pressure is heated, its specific enthalpy increases. In the liquid refrigerant region, when the temperature reaches the boiling point (saturated liquid), vapors are generated, thus resulting in moist vapors. A point, where the moisture has completely vaporized by further heating, is called the saturated vapor. When heat is applied to the saturated vapor, the temperature rises to form the superheated vapor region.

[Critical point]

When the refrigerant pressure increases up to a limit, the refrigerant vaporizes without boiling. This vaporization point is called the critical point. Since there is no practical occurrence of the critical point, some P-h Charts are produced at or below the critical point.

Fig.2-3



Q. 2

How is the state and what is the dryness factor at the point having a pressure of 0.7MPa abs and a specific enthalpy of 340 kJ/kg? (R22)

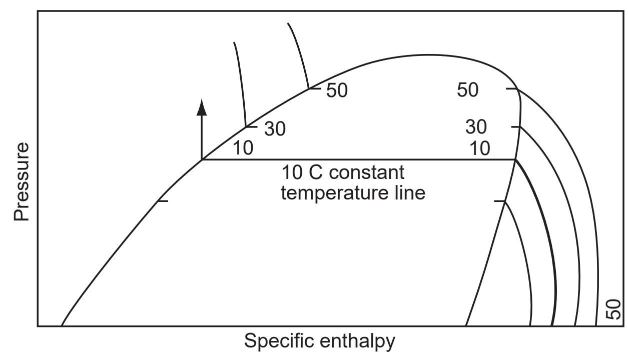
2.1.4 Temperature: t (℃)

When the points of equal refrigerant temperature are connected with lines throughout the sub-cooled liquid, moist vapor, and superheated vapor regions, these lines are called the constant temperature lines.

The constant temperature lines show up as vertical lines in the sub-cooled liquid region, and parallel to the constant pressure lines in the moist vapor region. In the superheated vapor region, they show up as downward-sloping curve.

Temperature graduation is marked in 10˚C increments and numerical values in 20˚C increments.

Fig.2-4



Q. 3

In which of the following regions is the state at a pressure of 0.4MPa abs and a temperature of 60˚C represented? Furthermore, find the specific enthalpy value in the state? (R22)

(1) Moist vapor region
(2) Superheated vapor region
(3) Sub-cooled liquid region

Q. 4

In which of the following regions is the state at a pressure of 0.8MPa abs and a temperature of 0˚C represented? Furthermore, find the specific enthalpy value in the state? (R22)

(1) Moist vapor region
(2) Superheated vapor region
(3) Sub-cooled liquid region

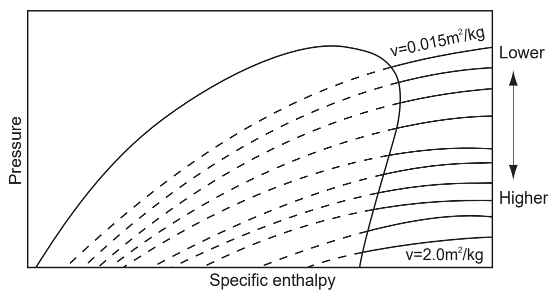
2.1.5 Specific volume: v [m^3/kg]

The volume occupied by 1 kg mass of refrigerant is the specific volume. Lines that connect the points of equal volume are the constant volume lines. The values are written on the right side of the superheated vapor region. The scale is logarithmic, while the numerical values can be read without paying much attention to the scale.

The larger the specific volume of refrigerant vapor is, the lower the gas density becomes. In other words, the gas becomes lighter in weight. By contrast, the smaller the specific volume is, the higher the gas density becomes, that is, the gas becomes heavier in weight.

Sometimes, these constant volume lines are shown with broken lines, or the lines are omitted in the moist vapor region.

Fig.2-5



Q. 5

Find the value of the specific volume and the specific enthalpy of refrigerant vapor at a pressure of 0.4MPa abs and a temperature of 30˚C. (R22)

2.1.6 Dryness factor: X

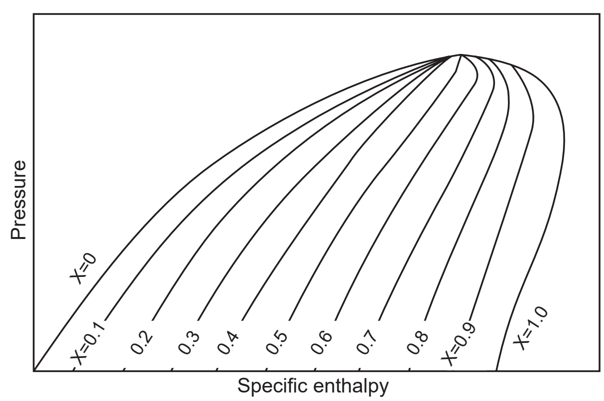
In the liquid/vapor mixture state, that is, in the moist vapor region, the percentage of vapor in the mixture is called the dryness factor. Lines drawn by connecting points of equal dryness factor are called the constant dryness lines.

Dry saturated vapors have a 1.0 dryness factor. If the dryness factor is 0.3, it means that 30% of the moist vapor is dry saturated vapor and 70% is saturated liquid.

However, this is the percentage by weight of refrigerant.

The dryness factor strictly represents the percentage of vapor in the moist vapor region.

Fig.2-6



Q. 6

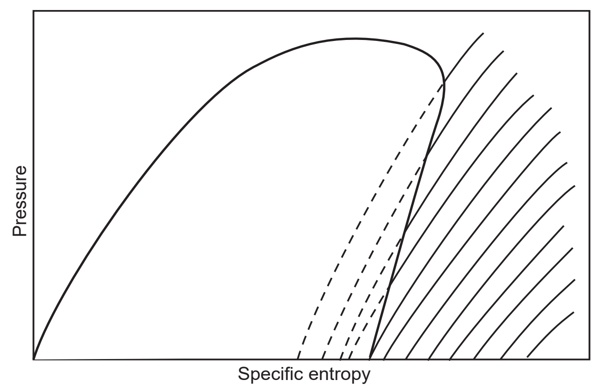
Find the value of the dryness factor of moist vapor having a specific enthalpy of 240 kJ/kg and a pressure of 0.2MPa abs. (R22)

2.1.7 Specific entropy: s [kJ/(kg·K)]

The lines which connect the points of equal specific entropy are called the constant entropy lines. There may be the cases where these lines are drawn only in the superheated vapor region with steep upward-sloping line or extended up to the moist vapor region. In the latter case, pay attention so as not to confuse with the constant dryness factor lines.

The compression process of refrigerant with a compressor completes in an extremely short period of time. Therefore, it is normally assumed that there is no heat exchange between the refrigerant and the surroundings. In other words, compression occurs with constant specific entropy. This is called an adiabatic compression. In the adiabatic compression, the conditions vary along the constant specific entropy lines.

Fig.2-7



Note: The specific entropy is scientifically defined as follows.

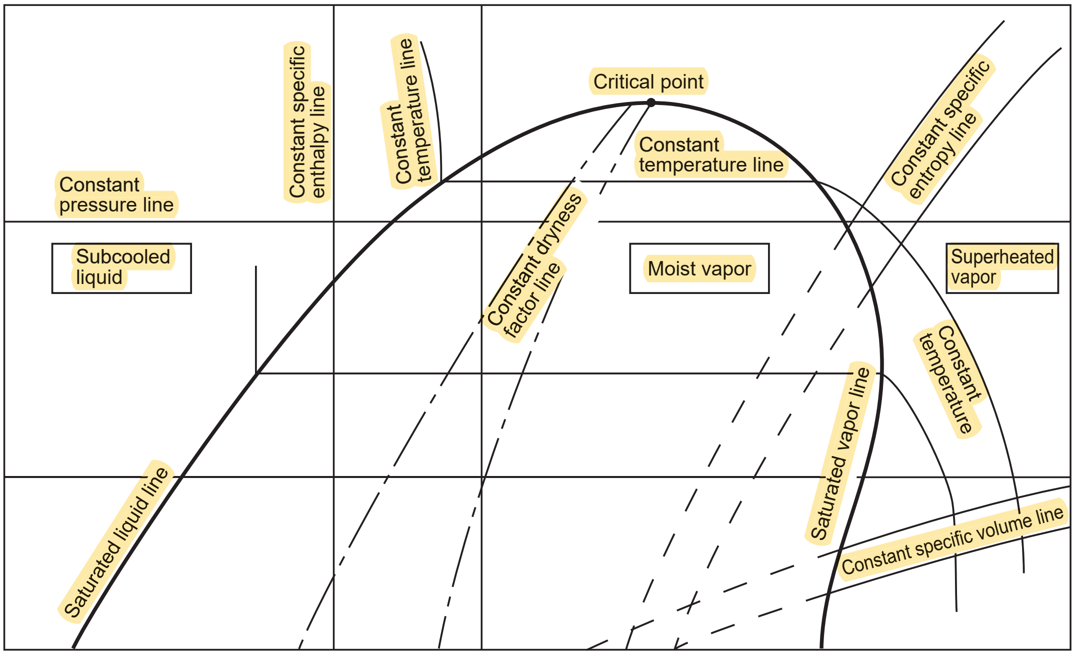
The amount obtained by dividing the heat amount transferred to a material of unit mass at a given temperature by the absolute temperature is taken as the increase of the specific entropy. When heat amount of dQ is transferred to a material of absolute temperature T, the increase of the specific entropy dS is calculated with the following formula.

$$dS = dQ/T$$

This "S" is defined as "specific entropy".

2.1.8 Summary

Fig.2-8



Exercise 1

Put down from Point A to Point E shown in the following table on the P-h Chart (R22) and fill in blanks (1) to (20) in the table with respective numerical values obtained from the Chart using such points. (If the column which cannot be filled from the Chart, fill it with an oblique line.)

Table 2-1

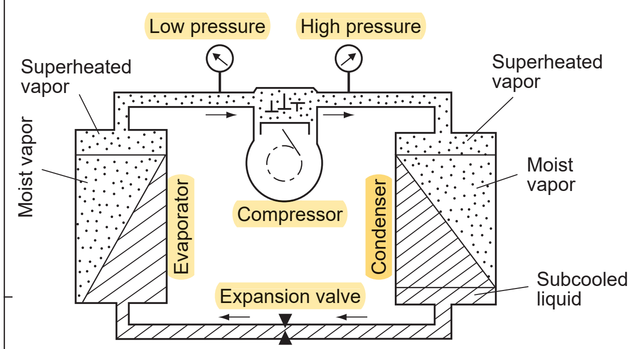
	P Absolute pressure MPa abs	t Temperature C	h Specific enthalpy kJ/kg	s Specific entropy kJ/(kg•K)	v Specific volume m^3/kg	x Dryness factor
Point A	0.8	80	(1)	(2)	(3)	(4)
Point B	1.0	(5)	200	(6)	(7)	(8)
Point C	0.2	(9)	350	(10)	(11)	(12)
Point D	0.4	(13)	450	(14)	(15)	(16)
Point E	(17)	0	(18)	(19)	0.1	(20)

2.2 How to draw refrigeration cycle

2.2.1 Vapor compression refrigeration cycle

Chiller and air conditioners consist of four major components such as evaporator, compressor, condenser, and expansion valve. The refrigerant flows through these components and the process of evaporation → compression → condensation → expansion repeats to carry out refrigeration. This process is called the refrigeration cycle.

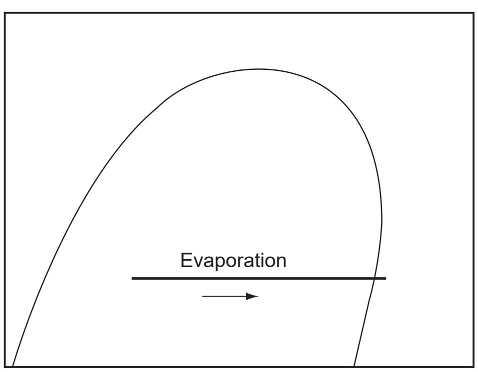
Fig.2-9



1. Evaporation (Change of phase in the evaporator)

The evaporation is a process in which the low-temperature low-pressure liquid refrigerant evaporates while removing heat from the indoor air or moisture. On the P-h Chart, this change of phase is represented by drawing a line from left to right with a constant pressure line, that is, a horizontal line.

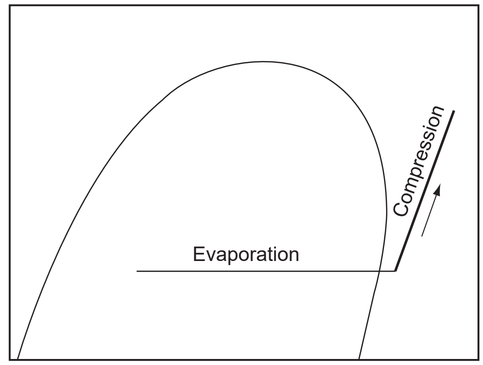
Fig.2-10



2. Compression (Change of phase in the compressor)

The compression is a process in which the compressor sucks in gases generated through the evaporation process and compresses the gases into high-temperature high-pressure superheated vapor. This process is taken as the adiabatic compression, that is, the constant specific entropy change.
In general, the suction gas into the compressor has a superheated degree of 5˚C. Therefore, on the P-h Chart, this change of phase stage is represented by drawing an upward-slopping line from the right side of the saturated vapor line, along the constant specific entropy line.

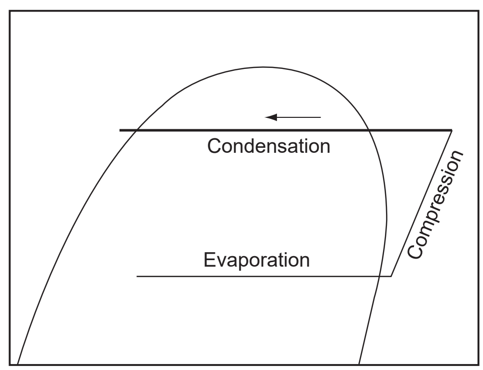
Fig.2-11



3. Condensation (Change of phase in the condenser)

The condensation is a process in which the high-temperature high-pressure discharge gas from the compressor is condensed (liquefied) through cooling water or outdoor air in the condenser. On the P-h Chart, this change of phase is represented by drawing a line from right to left with a constant pressure line, that is, a horizontal line.

Fig.2-12



4. Expansion (Change of phase in the expansion valve or capillary tube)

The expansion is a process in which the pressure of the condensed liquid refrigerant is reduced through the expansion valve (or capillary tube) to an evaporation pressure required. In this process, since there is no heat transmission between the refrigerant and the surroundings, the phase changes according to the constant specific enthalpy.
In general, the liquid refrigerant at the inlet of the expansion valve is sub-cooled by 5˚C below the condensing temperature. Therefore, on the P-h Chart, this change of phase is represented by drawing a vertical line from top to bottom from the left side of the saturated liquid line.